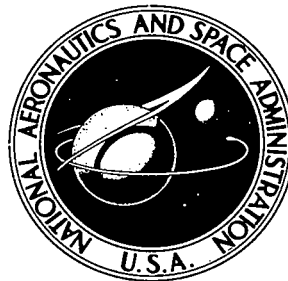


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**APOLLO EXPERIENCE REPORT -
THERMAL DESIGN OF APOLLO LUNAR
SURFACE EXPERIMENTS PACKAGE**

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16. Abstract The evolution of the thermal design of the Apollo lunar surface experiments package central station from the basic concept to the final flight hardware is discussed, including results of development, prototype, and qualification tests that were used to verify that the flight hardware would operate adequately on the lunar surface. In addition, brief discussions of the thermal design of experiments included in the experiments package are presented. The flight thermal performance is compared with analytical results and thermal-vacuum-test results, and design modifications for future lunar-surface experiment packages are presented.					
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CONTENTS

Section	Page
SUMMARY	1
INTRODUCTION	1
CONFIGURATION	2
THERMAL DESIGN OF CENTRAL STATION	4
THERMAL DESIGN OF EXPERIMENTS	6
Passive Seismic Experiment	6
Lunar-Surface Magnetometer	7
Solar-Wind Spectrometer	8
Suprathermal-Ion-Detector Experiment and Cold-Cathode Ion Gage	8
Active Seismic Experiment	9
Heat-Flow Experiment	10
Charged-Particle Lunar-Environment Experiment	10
Cold-Cathode-Gage Experiment	11
THERMAL TEST PROGRAM	12
MISSION PERFORMANCE	12
CENTRAL-STATION PERFORMANCE	13
EXPERIMENT PERFORMANCE	14
COMPARISON OF FLIGHT, TEST, AND ANALYTICAL RESULTS	16
DESIGN MODIFICATIONS	17
CONCLUDING REMARKS	17
REFERENCE	18
APPENDIX — EARLY APOLLO SCIENTIFIC EXPERIMENTS PACKAGE	19

TABLE

Table		Page
I	EXPERIMENT ASSIGNMENTS FOR APOLLO LUNAR-LANDING MISSIONS	3

FIGURES

Figure		Page
1	The ALSEP in the stowed configuration	
	(a) Subpackage 1	2
	(b) Subpackage 2	3
2	The final central-station thermal design	4
3	The central-station assembly	4
4	The radiator support mechanism in stowed configuration	5
5	The PSE with the shroud in the deployed and stowed configurations	
	(a) Shroud stowed	6
	(b) Shroud deployed	6
6	The LSM in the deployed and stowed configurations	
	(a) Deployed	7
	(b) Stowed	7
7	A side view of the LSM parabolic reflector	7
8	The SWS in the stowed configuration	8
9	The SIDE/CCIG in the deployed configuration	8
10	The ASE system in the deployed configuration	
	(a) Mortar box and grenade-launcher assembly	9
	(b) Thumper assembly	9
11	Elements of the HFE	10

Figure		Page
12	The CPLEE in the deployed configuration	
	(a) Exterior view	11
	(b) Cutaway view	11
13	The CCIG in the deployed configuration	11
14	The Apollo 12 ALSEP central station deployed on the lunar surface	13
15	The deployed arrangement of the Apollo 12 ALSEP	13
16	A comparison of the average thermal-plate temperature, recorded during lunar-surface operations, with the analytically predicted temperature envelope	13
17	Sunshield temperatures recorded during the second and eighth lunations	14
18	Primary-structure temperatures recorded during the second and eighth lunations	14
19	The PSE internal temperatures recorded during the first three lunations	14
20	The LSM internal temperatures recorded during the second and eighth lunations	15
21	The SIDE internal temperatures recorded during the second and eighth lunations	15
22	The CCIG internal temperatures recorded during the second and eighth lunations	15
23	The SWS internal temperatures recorded during the second and eighth lunations	15
24	A comparison of average radiator temperatures, recorded during lunar-surface operations, with the analytically predicted temperatures	16
25	A comparison of internal primary-structure temperatures, recorded during lunar-surface operations, with analytically predicted temperatures	16
26	A comparison of sunshield temperatures, recorded during lunar- surface operations, with analytically predicted temperatures	16

Figure		Page
27	The ALSEP design for high-latitude deployment	17
A-1	The Apollo 11 PSEP configuration	
	(a) Subsystems	19
	(b) Subsystems components	19
A-2	The LRRR configuration	
	(a) Stowed	19
	(b) Deployed	19
A-3	A diagram of the internal structure of a PSEP isotope heater . . .	20
A-4	A comparison of PSEP radiator-plate temperatures, recorded during lunar-surface operations, with analytically predicted temperatures	20



APOLLO EXPERIENCE REPORT

THERMAL DESIGN OF APOLLO LUNAR SURFACE

EXPERIMENTS PACKAGE

By Robert S. Harris, Jr.
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SUMMARY

The design of the thermal-control system of the Apollo lunar surface experiments package is presented in this report. The evolution of the central-station thermal-control system, from the basic concept to the final flight design, is discussed in detail, including results of the test program used to verify that the final flight design would perform adequately on the lunar surface. The basic thermal-design features of the experiments also are presented.

The flight performance of the experiments package is assessed, and is compared with analytical and thermal-vacuum-test results. The central station provides the thermal control required to maintain the temperature of the electronic components within acceptable limits when the central station is exposed to the lunar-surface environment. Also, the thermal analytical models developed to predict central-station temperatures accurately describe central-station thermal performance on the lunar surface. Finally, thermal anomalies that occurred on some of the experiments and modifications to correct these anomalies are discussed.

INTRODUCTION

The Apollo lunar surface experiments package (ALSEP) contains a group of scientific instruments that are used to obtain long-term measurements of some physical and environmental properties of the moon and to transmit the scientific data obtained to receiving stations on earth. The data are used to derive information about the composition and structure of the moon, the magnetic field and atmosphere of the moon, and the solar wind. The ALSEP is composed of scientific experiment packages, a central station that collects and transmits data and distributes power to the experiments, and a radioisotopic thermoelectric generator (RTG) that supplies continuous electrical power to the central station. The entire package was designed to be deployed by pressure-suited astronauts on the lunar surface and to operate for a year or longer.

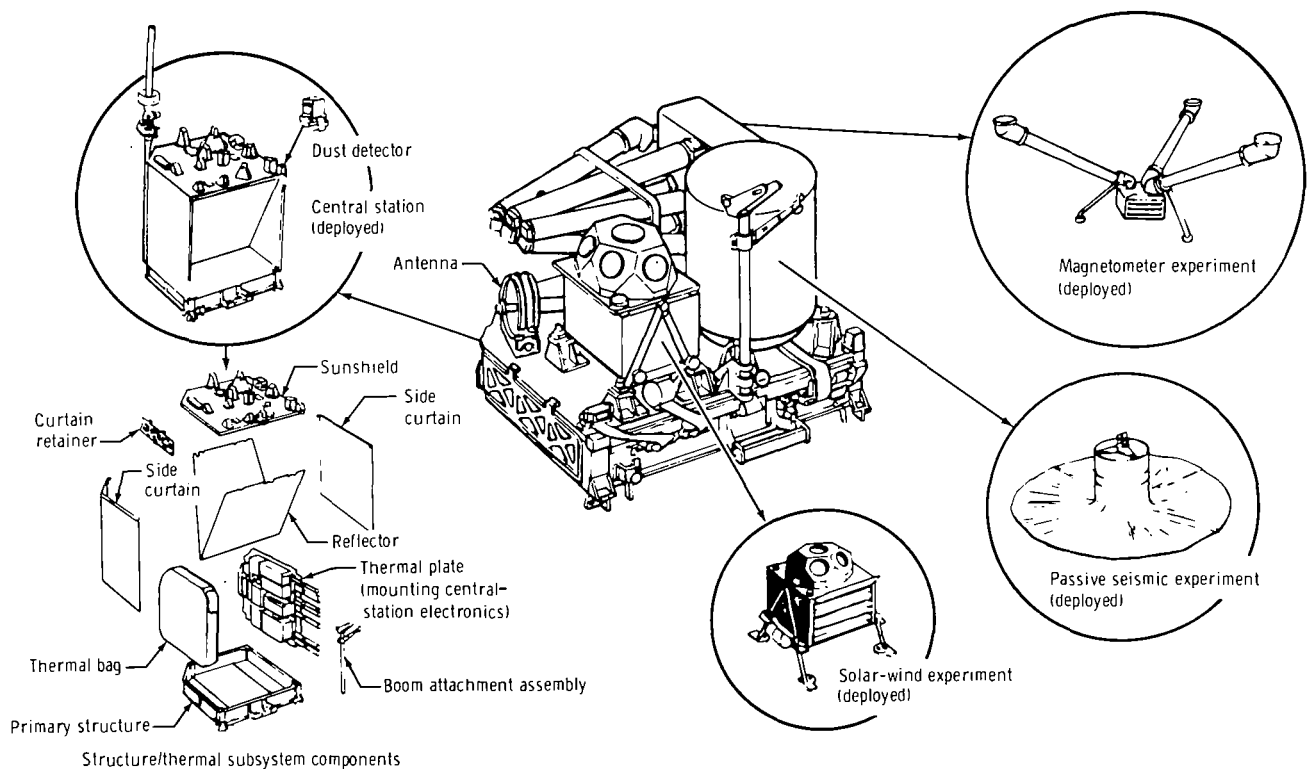


The ALSEP is assembled into two subpackages that are carried to the moon in the lunar module (LM). One subpackage contains the central station and the majority of the experiments; the other subpackage contains the remainder of the experiments, the RTG, and the other equipment used by the crewmen during lunar-surface operations. Although eight separate experiments are discussed in this report, no more than five experiment packages are included in any single ALSEP.

The thermal-control system maintains the temperatures of the ALSEP central station and the experiments within required limits for operation in the lunar environment. The thermal design of the ALSEP central station and results of thermal analyses and thermal-vacuum tests are discussed. Finally, the thermal performance of the first ALSEP deployed on the lunar surface is presented, and the central-station temperature variations are compared with analytically predicted temperatures.

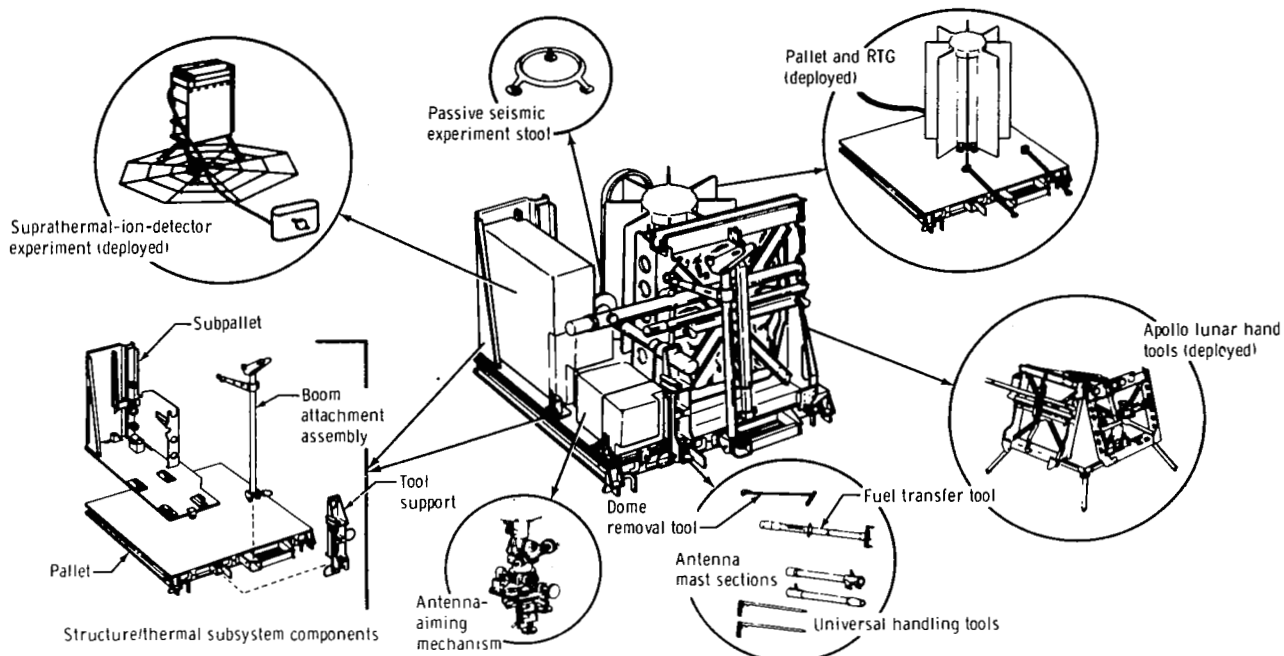
CONFIGURATION

The ALSEP equipment is stowed in the LM as illustrated in figure 1. On the moon, the ALSEP is deployed by the crewmen at a distance of at least 500 feet from the LM.



(a) Subpackage 1.

Figure 1.- The ALSEP in the stowed configuration.



(b) Subpackage 2.

Figure 1. - Concluded.

A maximum of five experiments is included in each ALSEP. Experiment assignments for each Apollo flight are outlined in table I. The version of the ALSEP carried on the Apollo mission, the first manned lunar landing, was simplified to reduce the time required for the deployment of the experiments. That version of the ALSEP, which was called the early Apollo scientific experiments package (EASEP), included a passive seismometer and a laser reflector (appendix).

TABLE I. - EXPERIMENT ASSIGNMENTS FOR APOLLO LUNAR-LANDING MISSIONS

Apollo mission	Experiments							
	PSE ^a	SIDE/CCIG ^b	SWS ^c	LSM ^d	CCGE ^e	ASE ^f	HFE ^g	CPLEE ^h
12	X	X	X	X				
13	X				X		X	X
14	X	X				X		X
15	X	X	X	X			X	
16	X			X		X	X	

^aPSE — passive seismic experiment.

^bSIDE/CCIG — suprathermal-ion-detector experiment/cold-cathode ion gage.

^cSWS — solar-wind spectrometer.

^dLSM — lunar-surface magnetometer.

^eCCGE — cold-cathode-gage experiment.

^fASE — active seismic experiment.

^gHFE — heat-flow experiment.

^hCPLEE — charged-particle lunar-environment experiment.

THERMAL DESIGN OF CENTRAL STATION

The ALSEP central station (fig. 2) houses the data subsystem, power-conditioning and distribution units, and electronics for the passive seismic experiment (PSE). The central-station thermal-control system is designed to protect those components from the lunar-surface environment. The central-station electronic components are attached to the bottom of a base plate, the upper surface of which serves as a radiator. To maintain the desired reliability of electronic components, the radiator-plate average temperature must be maintained within a 0° to 125° F operating range while the central station is exposed to the lunar-surface temperature extremes of approximately -300° to 250° F. In addition, the system is required to function satisfactorily when radiative properties of surfaces exposed to solar radiation are degraded by dust, ultraviolet radiation, or other phenomena.

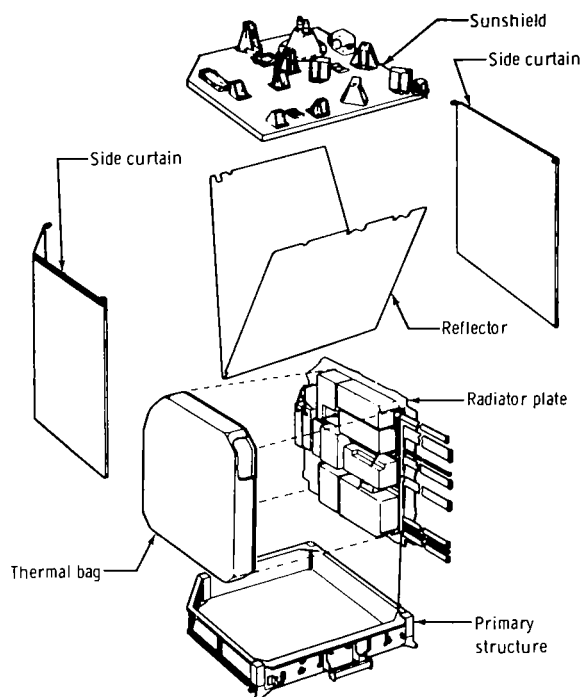


Figure 2. - The final central-station thermal design.

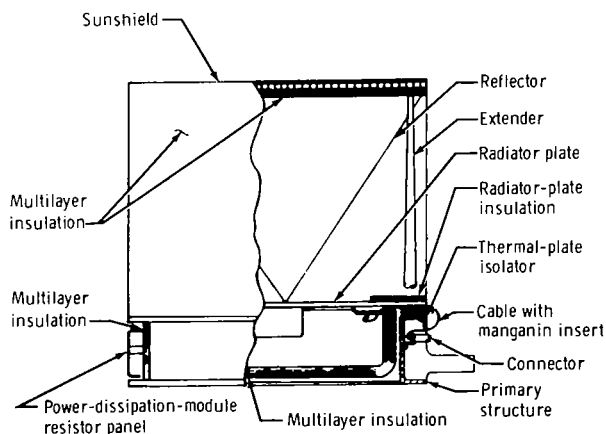


Figure 3. - The central-station assembly.

The central-station design includes multilayer insulation (fig. 3) to isolate the electronic components effectively from the widely varying lunar thermal environment. Also, a radiative coupling to the deep-space heat sink is maintained to dissipate internally generated heat. An insulated sunshield was incorporated into the design to protect the radiator plate from direct solar radiation during the lunar day. The electronic components are enclosed in 40 layers of aluminized Mylar with tissue-glass separators for radiation protection; a high-thermal-resistance support mechanism (fig. 4), located between the base plate and the primary structure, provides conductive isolation from extreme lunar-surface temperatures. Low-conductivity manganin inserts are used (fig. 3) to minimize heat leak through the wires and cables that penetrate the electronic compartment and are exposed to the lunar environment.

An analytical thermal model of the sunshield concept was used to establish the required height of the sunshield. Steady-state computer analyses were run for lunar-noon and lunar-night conditions. When the sunshield design was conceived, the

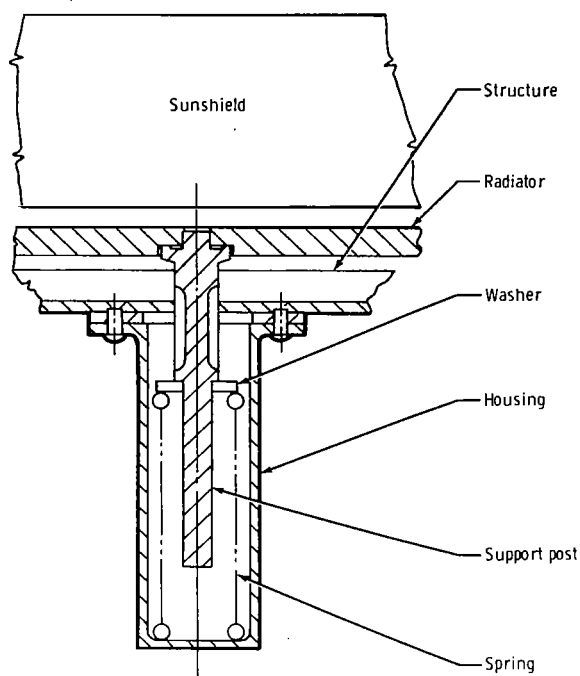


Figure 4. - The radiator support mechanism in stowed configuration.

internal power dissipation of the central station varied from 18.5 to 23.5 watts. With this power dissipation, a sunshield height of 8 inches above the radiator plate was needed to meet the 0° to 125° F base-plate temperature limits. The system, which was tested in a 20- by 27-foot thermal-vacuum chamber under simulated lunar-day and lunar-night conditions, met the temperature requirements.

Later in the program, the power-conditioning unit (PCU), which previously had been an independent unit with a separate thermal-control system, was incorporated into the central station. This change increased the central-station power dissipation to approximately 34 watts. Because of the increased power dissipation, the sunshield height had to be increased to 26 inches to provide an increased radiator exposure. This change also necessitated the addition of multilayer side curtains to prevent direct solar impingement on the radiator plate, and awnings were added to prevent direct impingement of solar radiation in the event of central-station misalignment.

The increased sunshield height allows excessive radiative coupling between the lunar surface and the radiator plate, increasing the temperature of the radiator plate beyond acceptable limits. To solve this problem, a V-shaped aluminized-Mylar specular reflector was incorporated between the radiator plate and the sunshield. A series of thermal-vacuum tests was conducted on a scale model of the central station to establish the optimum reflector arrangement. Based on these tests, a reflector angle of 66° was chosen. Also, a portion of the radiator plate had to be masked with multilayer insulation to reduce the effective radiator area. This insulation is used to maintain the radiator-plate temperature at an acceptable level during lunar night. Deployment training was indicative that alignment was not a problem; therefore, awnings were not necessary.

The primary components of the thermal-control system are the radiator plate with attached electronic components, an insulated sunshield and side curtains to prevent impingement of solar radiation on the radiator plate, multilayer insulation (fig. 3) and radiator-plate isolators to isolate components from lunar-surface temperature extremes, thermostatically controlled heaters to provide additional power dissipation on the radiator plate when required, and a power-dissipation module (fig. 3) to dissipate excess RTG power external to the central station during lunar day when the power is not required for thermal control of the experiments. The final design of the central-station thermal-control system was incorporated into a detailed analytical model for prediction of component temperatures during lunar-surface operation. A detailed discussion of the analytical methods used is contained in reference 1.

THERMAL DESIGN OF EXPERIMENTS

A description of the thermal-control-system design for each ALSEP experiment is given in the following sections. Each ALSEP experiment is required to provide its own thermal-control system with environmental requirements essentially identical to those of the central station. Any additional power necessary to meet the thermal-control requirements is to be supplied from the central station by the RTG. Analytical thermal models of the experiments were used to establish the required thermal-control-system design. The design temperature limitations were determined by reliability considerations and by scientific requirements.

Passive Seismic Experiment

The PSE (fig. 5) was designed to monitor lunar seismic activity, to detect meteoroid impacts, and to measure tidal deformations by the use of a set of triaxial, long-period seismometers and a short-period seismometer. The PSE sensor was designed to operate at a preset mean temperature of $126^{\circ} \pm 1^{\circ} \text{ F}$. The desired temperature variation during a lunation was $\pm 0.36^{\circ} \text{ F}$ of the preset mean temperature, and the maximum allowable variation to obtain minimum-acceptable seismic data was $\pm 18^{\circ} \text{ F}$ of the mean temperature. To meet the temperature-control requirements, the sensor had to be isolated from the external environment. This isolation was accomplished by means of a thermal shroud consisting of 20 layers of aluminized Mylar that cover the sensor and the lunar surface near the sensor. The shroud extension, which covers the lunar surface, reduces the effects of the widely varying lunar-surface temperatures on the temperatures of the sensor. In addition to the shroud, controlled electrical heaters are used to maintain the sensor temperature during lunar night. The operating mode of the heater assembly is controlled by command through heater-control circuits. The heater-control modes are automatic, thermostatic bypass (manual on), and off. The normal operation mode is the automatic mode, which provides power to the heater through a thermostatic-control circuit to maintain the preset temperature level of the sensor.

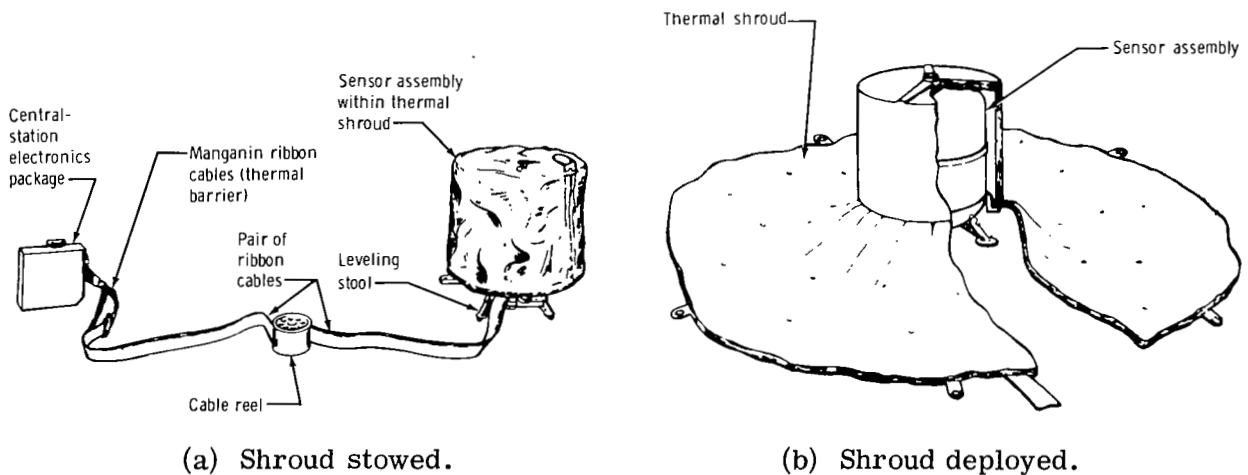
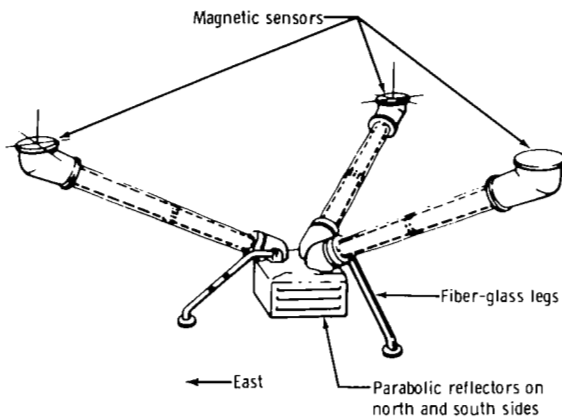


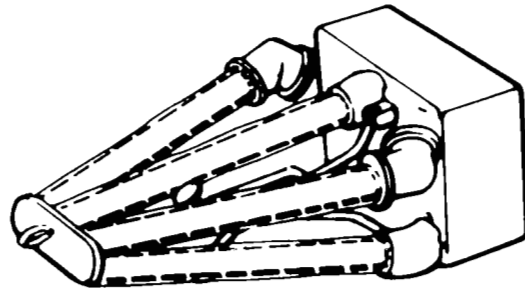
Figure 5. - The PSE with the shroud in the deployed and stowed configurations.

Lunar-Surface Magnetometer

The lunar-surface magnetometer (LSM) is designed to measure the magnitude and variations of the lunar-surface magnetic field. The objectives of the LSM investigation are to derive the electrical properties of the interior of the moon and to define more conclusively the interplanetary magnetic field that is diffused through the moon. The LSM consists of three magnetic sensors mounted in sensor heads and located at the ends of three 3-foot-long fiber-glass support arms (fig. 6). Each magnetic sensor is housed in a fiber-glass jacket and is wrapped with glass-felt insulation. Each of the three sensors is equipped with a thermostatically controlled 1-watt heater to maintain a 95° to 113° F temperature range. The upper flat surface of each sensor is left uncovered and painted with a white coating so that it serves as a thermal radiator. The support arms are mounted on a base structure that contains the electronics package and the mechanism for controlling the position of the magnetic sensors. The LSM electronic components are designed to operate in the range of -58° to 149° F.



(a) Deployed.



(b) Stowed.

Figure 6. - The LSM in the deployed and stowed configurations.

The temperature of the electronics package is controlled by a radiator array that consists of vertical low-emittance parabolic reflectors (fig. 7) and horizontal high-emittance radiating fins. The reflectors are designed to reflect energy from the lunar surface, and the fins are designed to dissipate internally generated heat into space. The electronics package is insulated, and the radiators are bonded to the electronics package. All external surfaces of the insulation subassembly are covered with thin fiber glass and coated with white paint. The structure is supported above the lunar surface by fiber-glass legs.

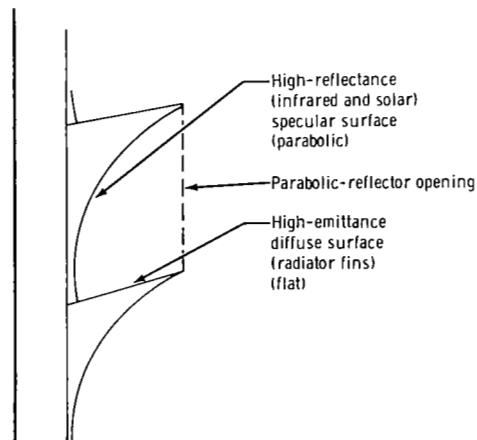


Figure 7. - A side view of the LSM parabolic reflector.

Solar-Wind Spectrometer

The purpose of the solar-wind-spectrometer (SWS) experiment (fig. 8) is to measure the energy, density, incidence angle, and temporal variation of the electron and proton components of the solar-wind plasma striking the lunar surface. Detection of the solar-wind electrons and protons is accomplished by means of seven Faraday cups that measure the charged-particle flux entering the cups. The open ends of the cups are pointed toward different, but overlapping, parts of the lunar sky.

The SWS thermal-control system is designed to maintain the temperature of the electronic components in a 14° to 167° F range. The SWS electronic components are mounted on a gold-plated fiber-glass housing. The thermal-control system uses three radiators on one vertical face, and multilayer insulation covers the other five faces of the electronics package. The radiators are a finned type and have parabolic reflectors mounted under each fin to reflect radiation from the lunar surface in a manner identical with the magnetometer radiators described in the preceding section. The insulation is alternate layers of aluminized Mylar and silk organza. During lunar night, an electrical heater maintains internal power dissipation at 6 watts and is activated by a temperature sensor when the temperature drops below 77° F.

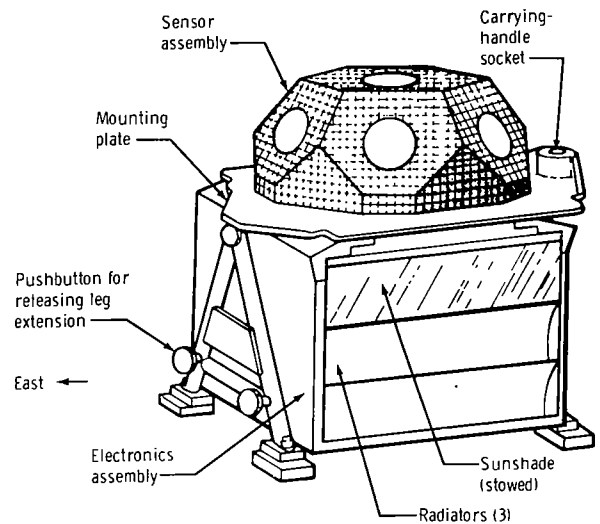


Figure 8. - The SWS in the stowed configuration.

Suprathermal-Ion-Detector Experiment and Cold-Cathode Ion Gage

The suprathermal-ion-detector experiment (SIDE) and the cold-cathode ion gage (CCIG) are combined as one unit (fig. 9). The purpose of the SIDE is to measure flux, number density, velocity, and energy per unit charge of positive ions in the vicinity of the lunar surface. The CCIG is included with the SIDE to determine the density of any lunar atmosphere, including variations associated with solar activity. The design temperature limits of the SIDE electronic components are -4° to 176° F. The SIDE thermal-control system consists of an inner housing assembly to which electronic components and detectors are mounted. The inner housing has gold-plated covers for low-emittance surface properties and is

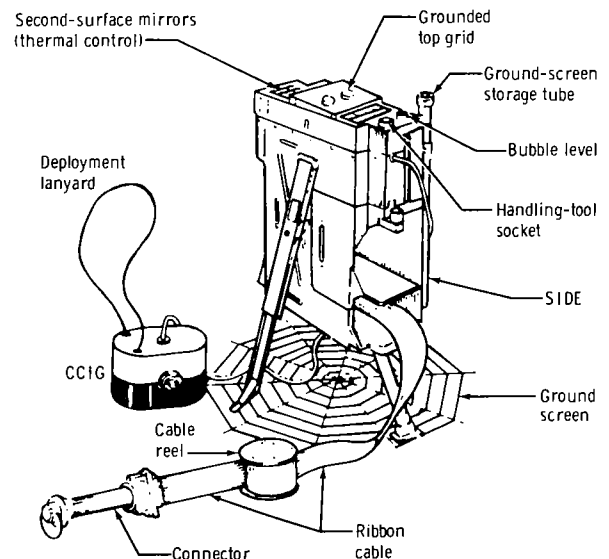


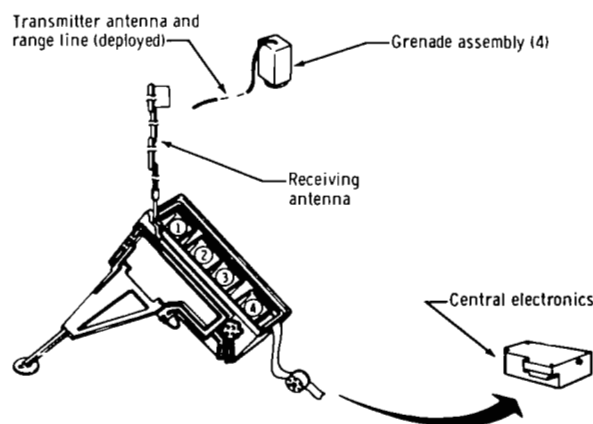
Figure 9. - The SIDE/CCIG in the deployed configuration.

suspended in an external housing that has gold-plated inner surfaces. The top of the external housing, the radiator and heat sink for the electronics package, is covered with mirrors to minimize solar-radiation input; the inner and outer housings are separated by means of plastic screws. A coating of white paint is applied to exterior surfaces, and further thermal control is obtained with electrical heaters, a 4-watt thermostatically controlled operational heater, and a 2-watt survival heater. The assembly is supported and isolated from the lunar surface by three fiber-glass legs. The outer housing also contains the CCIG, which is removed during the deployment of the experiment. The CCIG is deployed on the lunar surface approximately 4 feet from the SIDE, and its temperature fluctuates with the lunar-surface temperature.

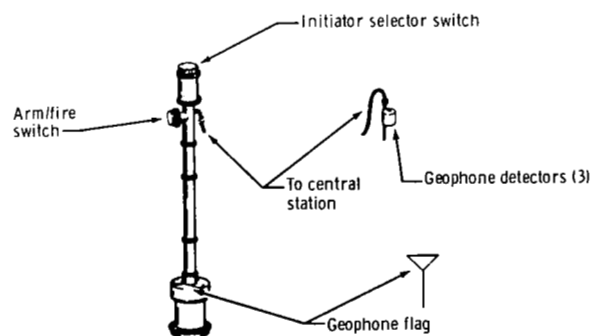
Active Seismic Experiment

The primary function of the active seismic experiment (ASE) (fig. 10) is to monitor artificially generated seismic waves in the lunar surface. The ASE also can monitor natural seismic waves in its frequency range (3 to 250 hertz). Information acquired from this experiment will be helpful in the determination of the physical properties of the lunar-surface and the near-subsurface materials.

The ASE consists of a mortar package, a thumper device, geophones, and an electronics package that is located in the central station. The ASE uses two seismic-energy sources: the thumper (containing explosive initiators that are fired along the geophone lines by an astronaut) and the mortar package (containing four grenades that will be launched by telemetry command from earth). The mortar box is designed to maintain the internal components between -94° and 185° F. The internal temperature of the mortar box is maintained with aluminized-Mylar multilayer insulation on the sides and bottom, an aluminized-Mylar sunshield on top, a white thermal coating, and a 1.75-watt electrical heater.



(a) Mortar box and grenade-launcher assembly.



(b) Thumper assembly.

Figure 10. - The ASE system in the deployed configuration.

Heat-Flow Experiment

The heat-flow experiment (HFE) (fig. 11) is designed to measure the temperature gradient and thermal conductivity in the upper surface layers of the moon. The measurements obtained from this experiment can be used for calculation of lunar heat flow and will provide information about the composition and physical state of the interior of the moon.

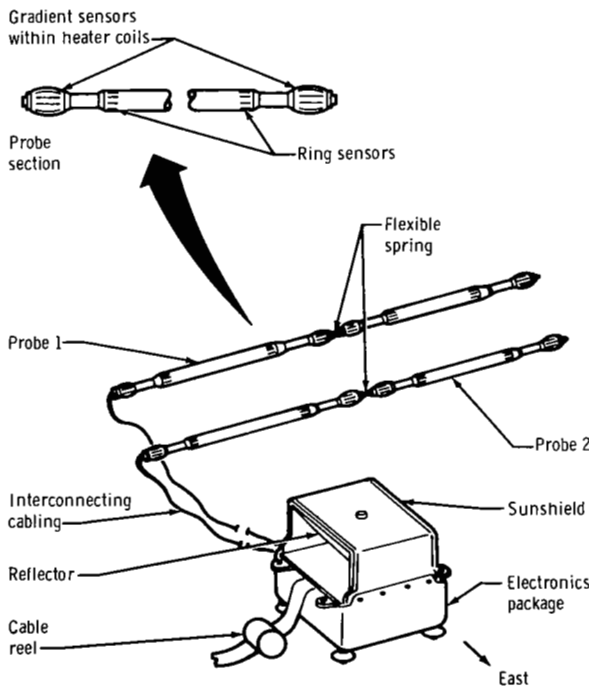


Figure 11. - Elements of the HFE.

The major components of the HFE are sensor probes and an electronics package. The probes are epoxy/fiber-glass tubular structures that support temperature sensors, heaters, and associated wiring. The electronics package contains the printed circuit boards used for control of the experiment. The operational temperature limits of the electronic components are 32° to 140° F. Temperature control is accomplished by both passive and active means. The passive-thermal-control system consists of a sunshield for solar-input reflection and specular reflectors that aid in dissipation of internally generated heat. Also, the electronics package is supported by fiber-glass legs and is contained in a multilayer-insulation bag enclosed in a fiber-glass structure. Thermal-control coatings are used on external surfaces. The thermal design is similar to that of the central station described in a preceding section. Active thermal control is provided by a thermostatically controlled heater (2.55 watts) mounted on the electronics package.

Charged-Particle Lunar-Environment Experiment

The charged-particle lunar-environment experiment (CPLEE) (fig. 12) was designed to measure the energy distribution, time variations, and direction of proton and electron fluxes at the lunar surface. The CPLEE consists of two detector packages (analyzers) oriented in different directions for minimum exposure to the ecliptic path of the sun. Each detector package has six particle detectors; five provide information about particle energy distribution, and the sixth provides high sensitivity during low fluxes.

The CPLEE is designed to operate within the temperature range from -50° to 150° F. When the instrument is nonoperational, the survival temperature range is -60° to 160° F. The CPLEE thermal-control system consists of multilayer insulation on four sides and on the bottom of the package and a radiator plate with second-surface mirrors on the top. The insulation is composed of alternate layers of aluminized Mylar

and fiber glass. The experiment configuration is shown in figure 12. In addition to the insulation, the CPLEE has thermostatically controlled heaters (3.0 watts) mounted to the underside of the radiator plate that maintain the temperature within required limits during the lunar night. The automatic control can be bypassed by command to turn the heaters on or off.

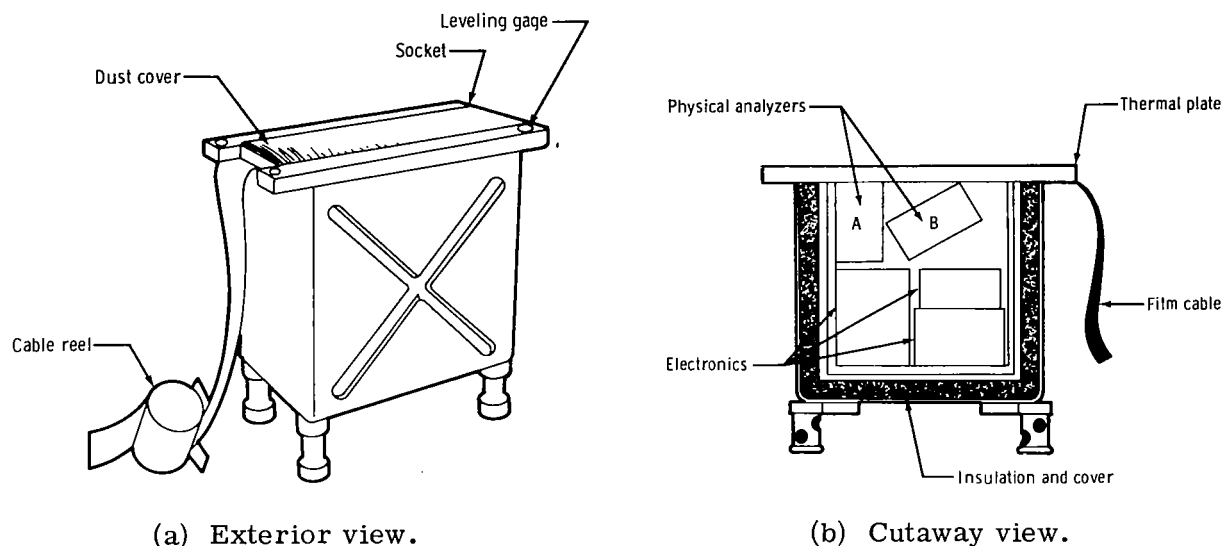


Figure 12. - The CPLEE in the deployed configuration.

Cold-Cathode-Gage Experiment

The cold-cathode-gage experiment (CCGE) (fig. 13) is composed of a cold-cathode ion gage and the associated electronics. The purpose of the experiment is to measure the density of the lunar atmosphere, including any temporal variations of a random nature or variations associated with lunar local time or solar activity. The experiment can be used to measure the loss rate of contaminants left in the landing area by the astronauts or the LM.

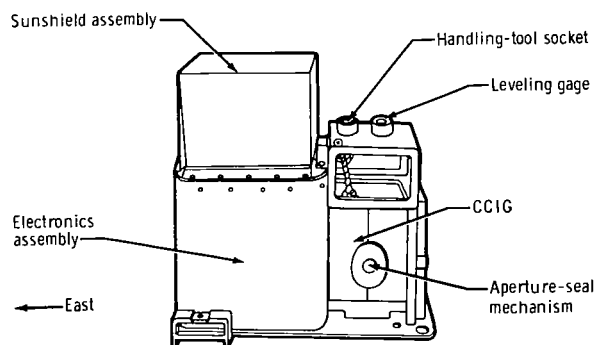


Figure 13. - The CCIG in the deployed configuration.

The design temperature limits of the CCGE electronics are -4° to 176° F during normal operation on the lunar surface. The electronic components are attached to a radiator plate and are shaded from direct sunlight by a sunshield (fig. 13). A reflector is used to provide the radiator with a deep-space field of view and to reduce heat input from the lunar surface. Also, a 4.5-watt electrical heater was used to maintain the internal temperature during nonoperating periods and to assist in thermal control during normal lunar-night operations.

The CCGE electronic components are housed in a fiber-glass case and are wrapped with aluminized-Mylar insulation to reduce heat leaks from the lunar surface. The assembly was enclosed in a fiber-glass structure, and a white thermal-control coating was applied to external surfaces to assist in maintaining the required temperatures.

THERMAL TEST PROGRAM

The thermal design of the ALSEP central station and experiments was verified by means of a series of system-, experiment-, and component-level thermal-vacuum tests. The test series included development, prototype, qualification, and flight-acceptance tests. System-level tests were conducted under simulated lunar-environment conditions in a thermal-vacuum chamber 20 feet in diameter by 27 feet in length. Additional tests on various experiment packages and on scale models of the central station were conducted in several smaller chambers. For the system-level tests, solar simulation was provided by infrared lamps located above the central station and experiment packages. The lamps were controlled so that the level of energy absorbed by a surface was equivalent to that absorbed by the same surface in the lunar environment under nominal and worst-case surface conditions. Control was accomplished by monitoring the energy absorbed by a radiometer with the same radiative properties as the surface absorbing the radiation. A 14- by 14-foot lunar plane was designed to simulate the lunar-surface temperature extremes of -300° to 250° F. The heat sink of space was simulated by liquid-nitrogen-cooled walls.

The results of the ALSEP test program were indicative of favorable temperature distributions on all central-station components, and good temperature correlation was obtained with the results of analytical predictions (ref. 1). It was proven in the test program that the ALSEP thermal-control system would maintain component temperatures within acceptable operating limits during operation on the lunar surface.

MISSION PERFORMANCE

The first flight-model ALSEP was deployed on the lunar surface during the Apollo 12 mission during November 1969. This ALSEP array included the PSE, SWS, LSM, and SIDE. The Apollo 12 landing site was located at latitude $3^{\circ}12'$ S and longitude $23^{\circ}24'$ W. The Apollo 12 ALSEP was deployed on the lunar surface, as planned, approximately 600 feet west-northwest of the LM (fig. 14). The deployment arrangement is shown in figure 15.



Figure 14. - The Apollo 12 ALSEP central station deployed on the lunar surface.

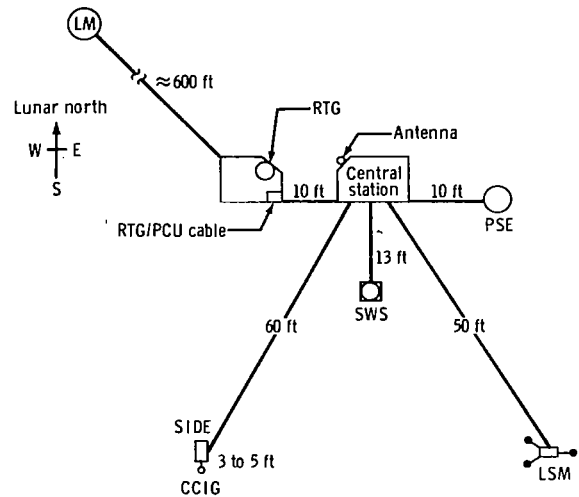


Figure 15. - The deployed arrangement of the Apollo 12 ALSEP.

CENTRAL-STATION PERFORMANCE

The average central-station radiator-plate temperatures for the second and eighth lunations are plotted in figure 16 and include a comparison with the postflight analytically determined temperature envelope for the actual deployment configuration. The predicted radiator-plate temperatures compare favorably with the actual temperatures encountered during the mission. The average radiator-plate temperature during the lunar day was lower than was predicted. The maximum radiator-plate temperature was 97°F during the first lunar day, compared with the expected value of approximately 125°F . The minimum radiator-plate temperature during lunar night was 0°F because the central-station heater was turned on at that temperature. The estimated minimum temperature that would have been reached without the heater was -5°F . With the central-station heater operating, the average radiator-plate temperature stabilized at 21°F during lunar night. The most probable cause of the lower central-station operating temperature was the failure of the radiator edge mask to deploy completely, thereby exposing more radiator area.

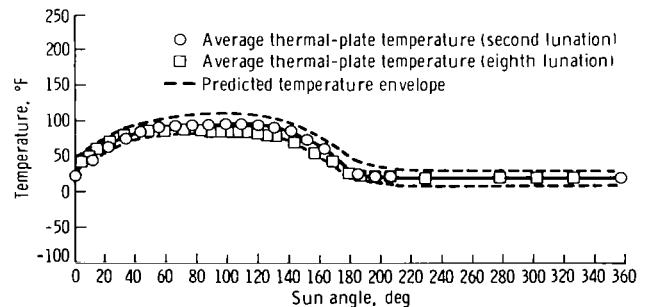


Figure 16. - A comparison of the average thermal-plate temperature, recorded during lunar-surface operations, with the analytically predicted temperature envelope.

Central-station sunshield and primary-structure temperature variations during typical lunations are plotted in figures 17 and 18, respectively. Primary-structure temperatures compare favorably with preflight predicted values.

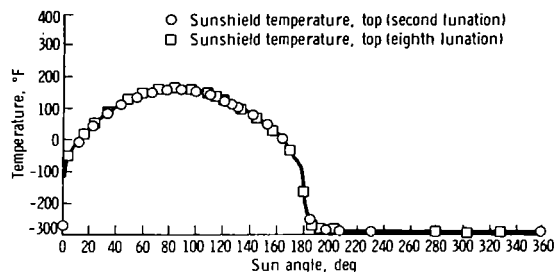


Figure 17. - Sunshield temperatures recorded during the second and eighth lunations.

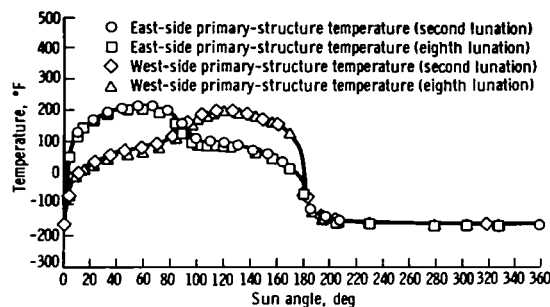


Figure 18. - Primary-structure temperatures recorded during the second and eighth lunations.

EXPERIMENT PERFORMANCE

The temperature variations of the PSE sensor during the first three lunar-day/lunar-night cycles are plotted in figure 19. The operational temperature-measurement limits were from 107° to 143° F. The temperature of the PSE sensor reached a maximum of 134° F during the first lunar day and increased to a maximum of approximately 145° F during the third lunar day. Since the third day of operation, the maximum temperature has remained at approximately the same level. During the first two lunar nights, the sensor temperature dropped below the lower limit of 107° F. The minimum sensor temperature cannot be established because of the instrumentation limit of 107° F, although the estimated minimum was 75° F. At the beginning of the third lunar night, the PSE sensor Z-axis leveling motor was commanded on, dissipating an additional 3.05 watts inside the experiment, and the sensor temperature stabilized at 126° F. This method of operation was continued through all subsequent lunar-night operations. The out-of-tolerance condition of the PSE considerably reduces the possibility of obtaining complete lunar-surface tidal data.

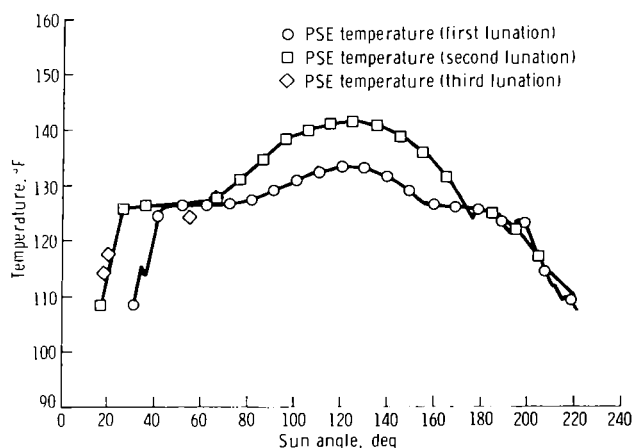


Figure 19. - The PSE internal temperatures recorded during the first three lunations.

In addition to the loss of tidal data, considerable noise was recorded at lunar sunrise and lunar sunset. The noise probably was caused by expansion and contraction of the multilayer-insulation skirt attached to the PSE. The most probable cause of the sensor temperature anomaly was that the insulation skirt had not been deployed properly. The skirt would not lie flat on the lunar surface and, therefore, did not provide the necessary insulation to maintain thermal control of the sensor. The Apollo 14 PSE incorporated a modified skirt with the addition of weights and stitching of the insulation to prevent deployment problems. Also, an increase in heater-power dissipation was incorporated to maintain lunar-night temperature.

The temperature response of the LSM during lunar-surface operation is plotted in figure 20. The maximum temperature limit of approximately 150° F was exceeded during lunar-day operation. The probable cause of the high-temperature condition was the contamination of thermal-control surfaces by lunar dust deposited during the deployment operation. From photographs of the LSM, it was determined that apparently the dust was deposited before the final stages of deployment, possibly during transport from the LM to the deployment site. The use of a dust cover over the package to prevent dust deposition during transport is planned for future Apollo missions. Also, a sunshade will be used over the electronics package to minimize solar illumination of the package during lunar noon.

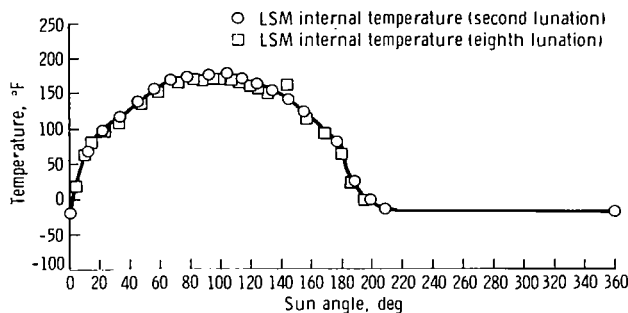


Figure 20.- The LSM internal temperatures recorded during the second and eighth lunations.

The responses of the SIDE and CCIG during lunar-surface operation are shown in figures 21 and 22, respectively. The required temperature limits of -40° to 176° F for SIDE electronic components were maintained during exposure to lunar-night and lunar-day conditions. However, because of erratic operation of the experiment during lunar day, the SIDE has not been operated continuously since the first lunation. Therefore, the temperatures during succeeding lunations have been considerably lower than during the first lunar day. The temperature responses of the SWS during operation on the lunar surface are plotted in figure 23. The response

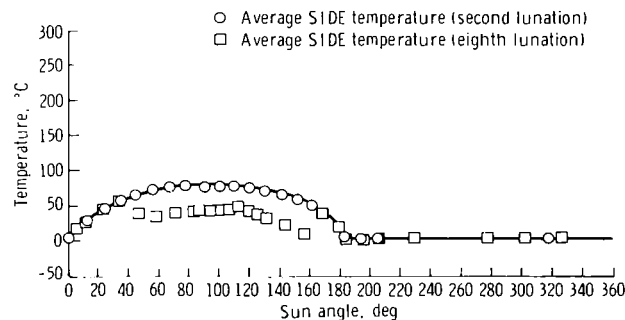


Figure 21.- The SIDE internal temperatures recorded during the second and eighth lunations.

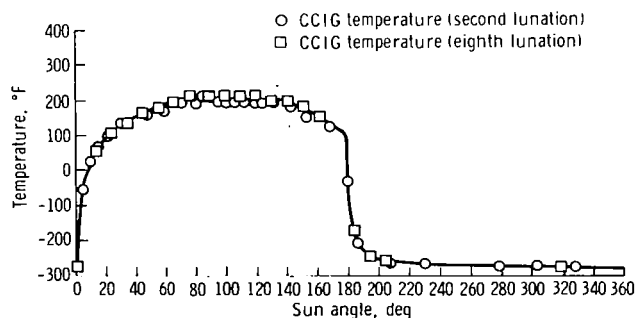


Figure 22.- The CCIG internal temperatures recorded during the second and eighth lunations.

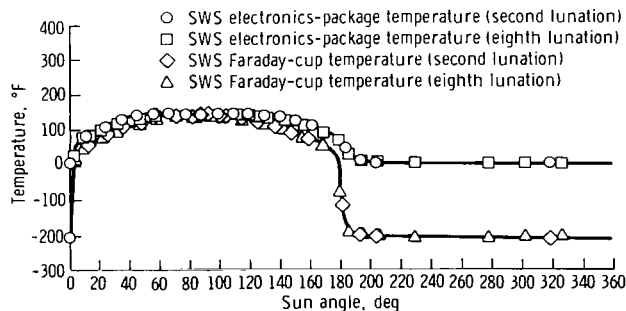


Figure 23.- The SWS internal temperatures recorded during the second and eighth lunations.

of the SWS electronic components occurred within the required temperature limits of 14° to 167° F, and the thermal-control system of the experiment performed as expected on the lunar surface.

COMPARISON OF FLIGHT, TEST, AND ANALYTICAL RESULTS

The average central-station radiator temperatures are compared with preflight analytical and test results in figure 24. The radiator temperatures were lower during lunar-surface operation than had been predicted, although postflight analysis, based on the actual configuration, provided good correlation (fig. 16). Preflight values of primary-structure temperatures are compared with actual lunar-surface temperature variations in figure 25. The flight results for these measurements were indicative of a close correlation with preflight predictions and thermal-vacuum-test results. Flight results for sunshield temperatures (fig. 26) were considerably higher than analytical and test results. Dust deposited on the sunshield during deployment was the probable cause of this discrepancy.

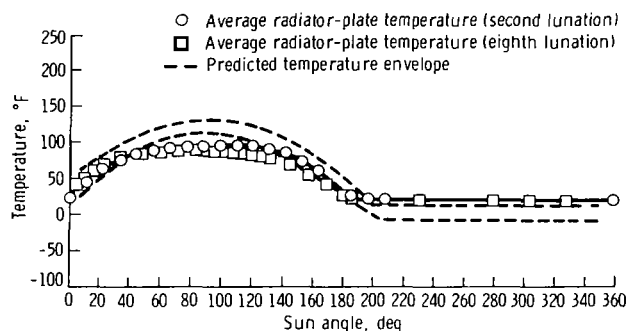


Figure 24. - A comparison of average radiator temperatures, recorded during lunar-surface operations, with the analytically predicted temperatures.

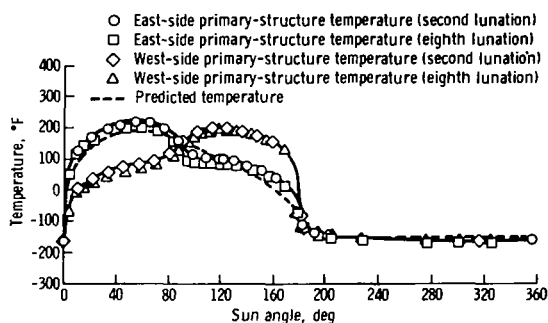


Figure 25. - A comparison of internal primary-structure temperatures, recorded during lunar-surface operations, with analytically predicted temperatures.

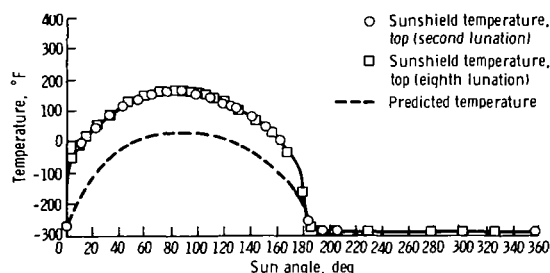


Figure 26. - A comparison of sunshield temperatures, recorded during lunar-surface operations, with analytically predicted temperatures.

DESIGN MODIFICATIONS

Modifications to the central-station thermal design have been necessitated by a requirement to deploy the ALSEP at higher latitudes on the moon. The basic ALSEP design was intended to provide thermal control when deployed at latitudes $\pm 5^\circ$ from the lunar equator. However, selected deployment sites now include latitudes considerably more than 5° from the equator. For these deployment sites, it is necessary to close the side of the central station that would face the equator after deployment. This change was made so that no solar radiation would impinge directly on the radiator surface. The side was closed by use of a multilayer-insulation curtain (fig. 27). Additional modifications to the insulation mask on the radiator were required to obtain the radiating area necessary for maintaining adequate thermal control. With these design changes, the ALSEP central-station thermal-control system is capable of maintaining adequate thermal control at latitudes of as much as 45° from the lunar equator.

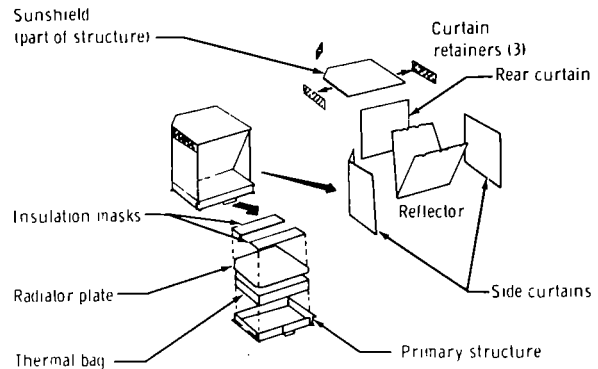


Figure 27. - The ALSEP design for high-latitude deployment.

CONCLUDING REMARKS

The first flight model of the Apollo lunar surface experiments package was deployed on the lunar surface during the Apollo 12 mission during November 1969. For approximately 2 years on the moon, the experiments package has transmitted scientific and engineering data to receiving stations on earth. The passive-thermal-control system that is used to maintain central-station temperatures has functioned satisfactorily during this operating period. The temperature of the central-station radiator plate, although lower than indicated in preflight predictions, has been maintained within the operating limits necessary to provide the required reliability of the central-station electronic components. However, several problems were encountered with thermal control of experiments on the first flight package, particularly the passive seismic and magnetometer experiments. Modifications have been made to these experiments to improve the thermal control for future flights.

The thermal-control system has provided the passive thermal control required to withstand the environments encountered during storage, translunar flight on board the lunar module, and deployment on the lunar surface. The basic thermal design has maintained central-station temperatures adequately during thermal-vacuum testing and during operation on the lunar surface. The analytical models that were developed to predict the thermal performance have described the central-station temperature

distribution accurately under lunar-surface conditions. With the described modifications, the central-station thermal design will provide the necessary thermal protection for the Apollo lunar surface experiments packages to be deployed on future lunar-landing missions.

Manned Spacecraft Center
National Aeronautics and Space Administration
Houston, Texas, December 8, 1971
514-40-73-90-72

REFERENCE

1. Collicott, H. E.; and McNaughton, J. L.: Thermal Control in a Lunar Environment. Bendix Tech. J., vol. 3, no. 1, 1970, pp. 1-15.

APPENDIX

EARLY APOLLO SCIENTIFIC EXPERIMENTS PACKAGE

During preparation for the first lunar-landing mission, Apollo 11, the decision was made to reduce the amount of time required to deploy scientific experiments. Therefore, the EASEP, a simplified version of the ALSEP, was developed for deployment during the first lunar-landing mission. The EASEP consisted of a passive-seismic-experiment package (PSEP) (fig. A-1), which was a combination of the PSE and the central station, and of the laser ranging retroreflector (LRRR) (fig. A-2).

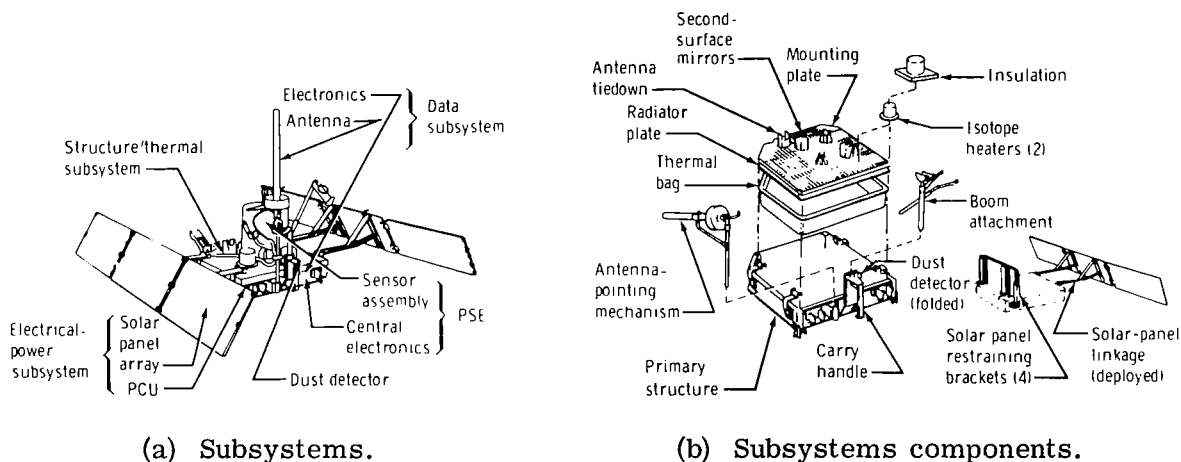


Figure A-1. - The Apollo 11 PSEP configuration.

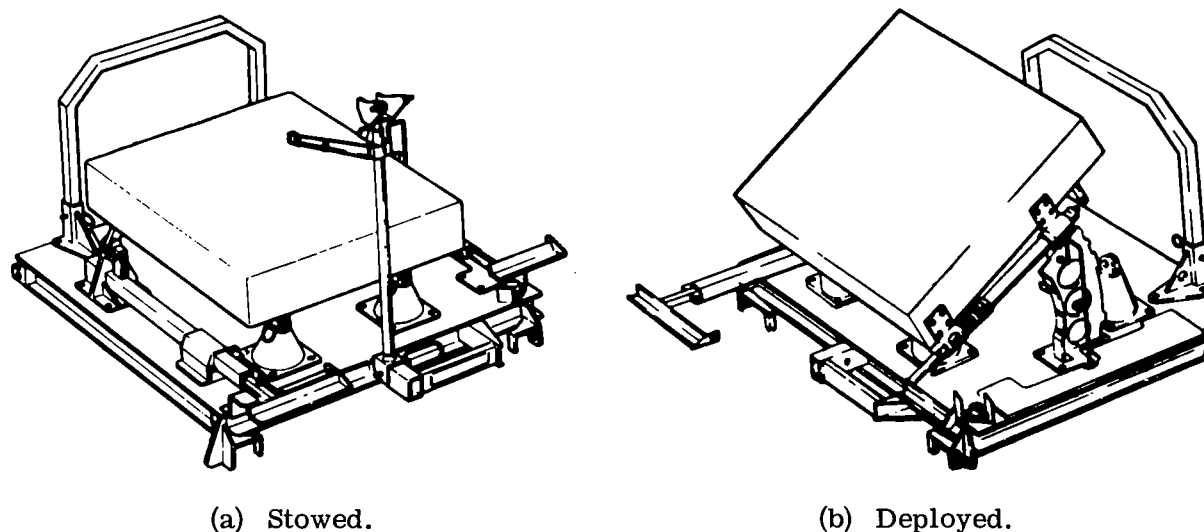


Figure A-2. - The LRRR configuration.

The PSEP thermal design was based on allowable average radiator-plate temperatures from -65° to 140° F. Power for the PSEP was supplied by a solar-cell array, and, therefore, the experiment did not operate during the lunar night. Hence, it was necessary to use isotopic heaters to maintain lunar-night temperatures greater than -65° F to ensure the required reliability. Two 15-watt isotopic heaters (fig. A-3) were attached to the radiator plate as shown in figure A-1. To reduce the solar-heat input during the lunar-day operation, the radiator plate was covered with second-surface mirrors that had a solar absorptance of approximately 0.08 and, at the same time, maintained a high emittance of approximately 0.8. The total area covered by the mirrors was 2.60 square feet.

The LRRR was a passive experiment designed to reflect laser radiation from earth-based stations. The support-structure pallet provided a structural base and a thermal decoupling of the reflector array from the lunar surface. A white, thermal-control coating (zinc-oxide/potassium silicate) was used on the pallet to provide a low temperature gradient between the reflector array and the pallet.

The predicted PSEP radiator-plate temperature is compared with the actual temperature recorded on the lunar surface in figure A-4. The actual radiator-plate temperature was approximately 50° F higher than was expected. The most probable cause of the overheating was optical degradation of the PSEP radiator/second-surface mirrors, resulting from contaminants deposited during the LM ascent. The depositions could have consisted of lunar dust, descent-stage debris, or combustion products. Analytically predicted temperatures for degraded second-surface mirrors also are given in figure A-4. The predicted temperatures for the degraded condition compare favorably with the actual temperatures recorded during lunar-surface operation.

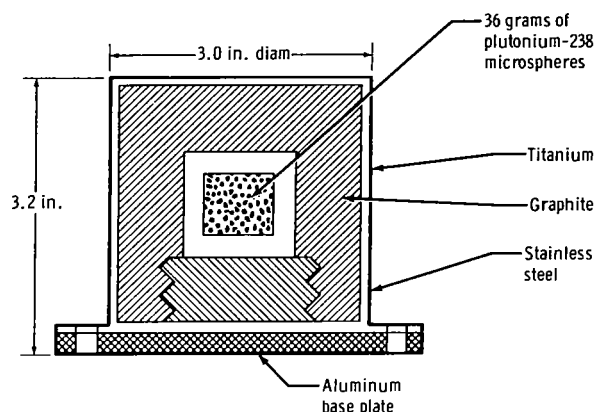


Figure A-3. - A diagram of the internal structure of a PSEP isotope heater.

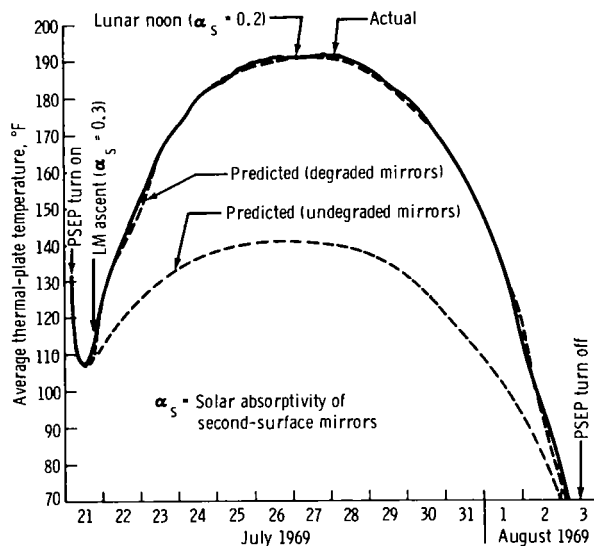


Figure A-4. - A comparison of PSEP radiator-plate temperatures, recorded during lunar-surface operations, with analytically predicted temperatures.